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ERTMS in an urban node

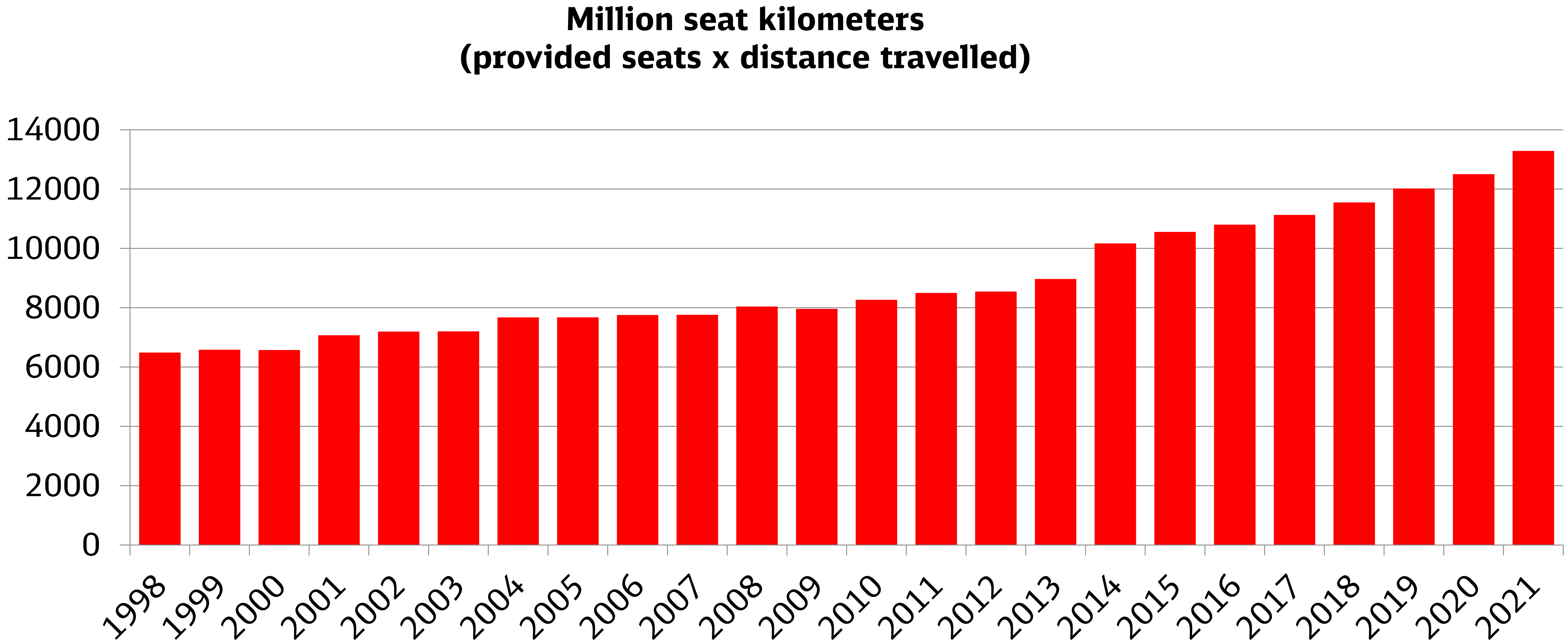
Spotlights on Stuttgart Digital Node (DKS)

Deutsche Bahn | Start-up coordination DKS/S21 (I.NA-SW)|
Stuttgart | 2023-06-29

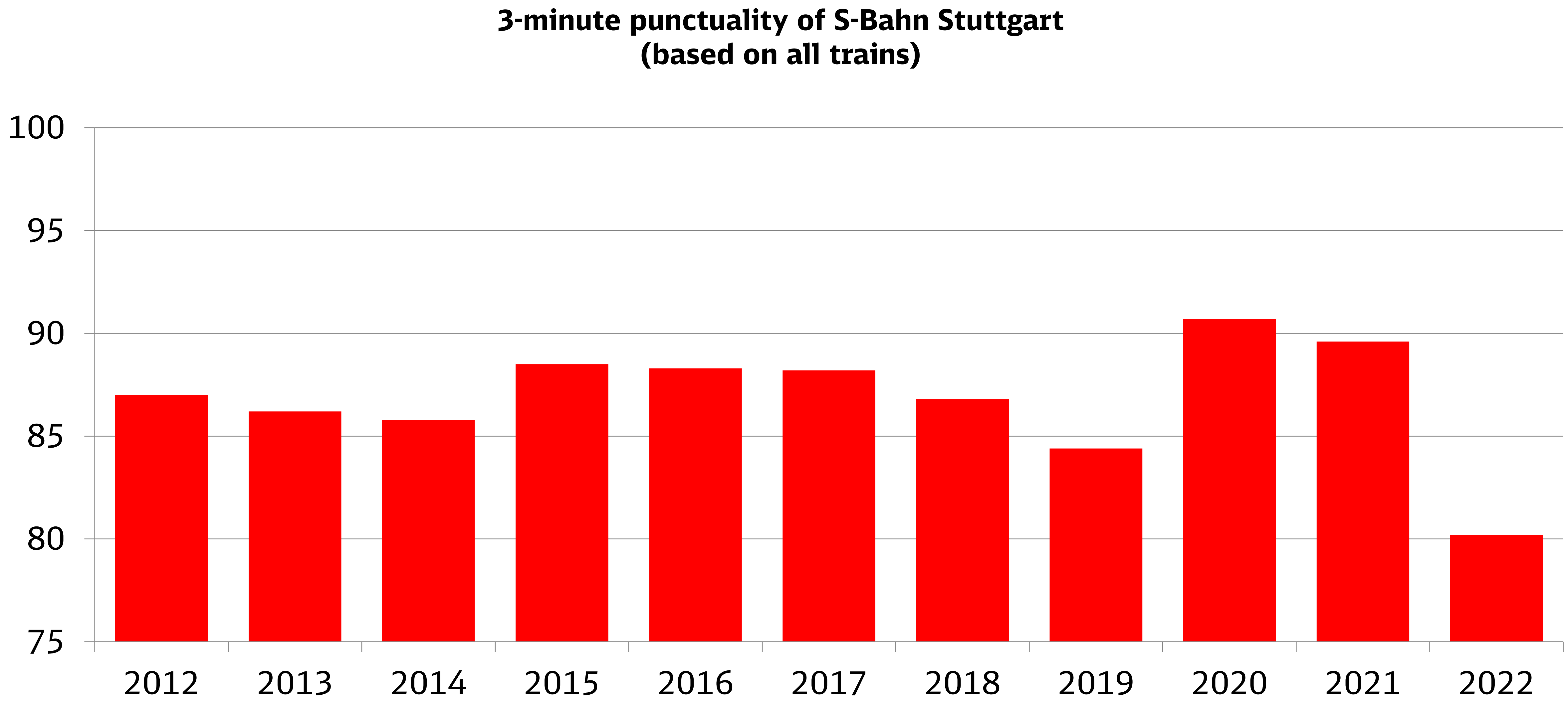
The Stuttgart Region in Baden-Württemberg: 3,654 km², 2.8 million inhabitants, 179 municipalities

Picture: Verband Region Stuttgart

Stuttgart's commuter railway system (S-Bahn) is a success story. However: More trains, longer trains and more passengers …



… led to a decline in punctuality.



Within the Stuttgart 21 project, the S-Bahn Core needed a new interlocking and new signaling in any case.

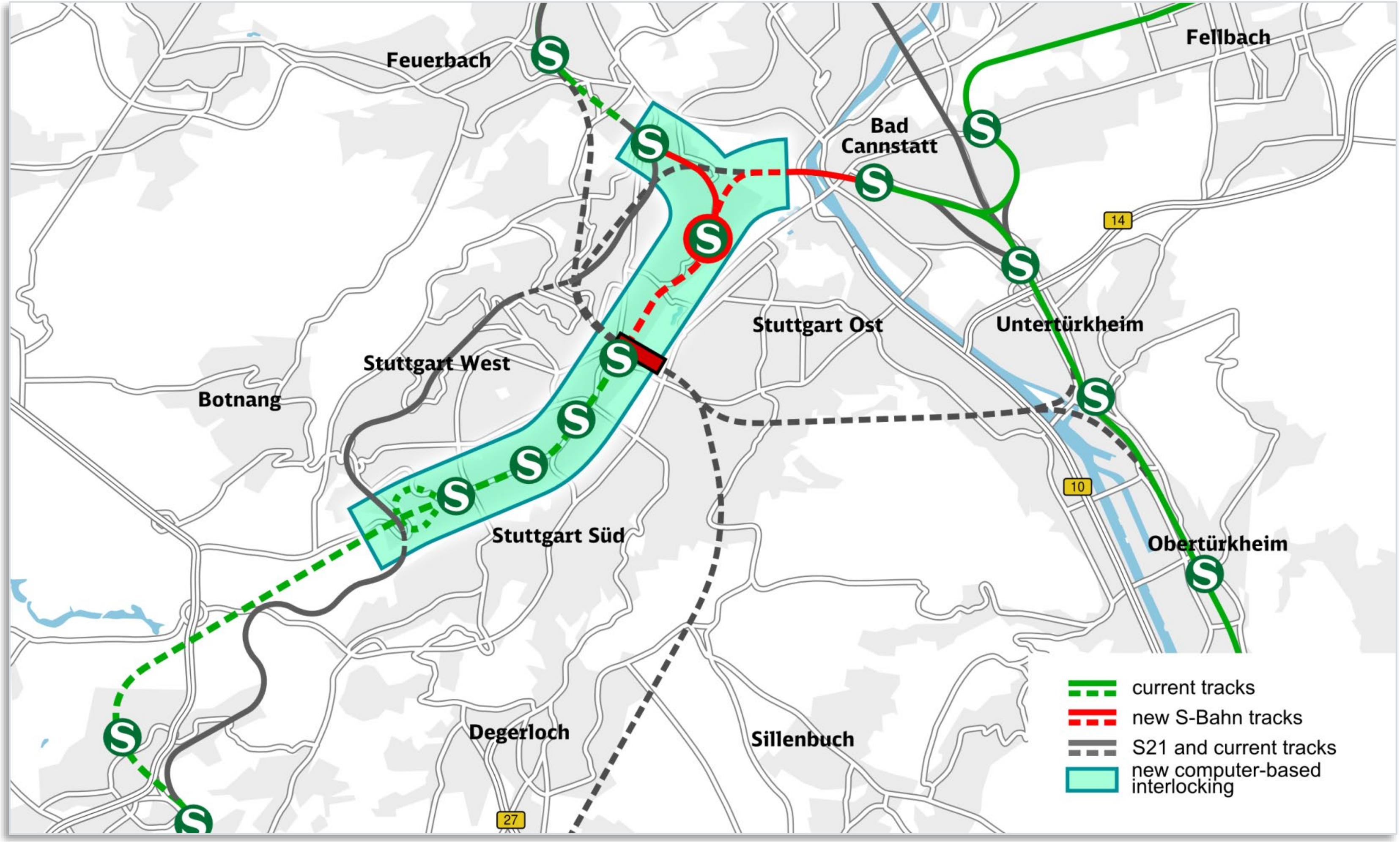


Figure: Core (*Stammstrecke*) of the Stuttgart S-Bahn system, including the control area of the new computer-based interlocking planed as of 2015.
Further reading: *ETCS as a carrier system for improved performance at S-Bahn Stuttgart*. Signal+Draht 6/2019 (https://bit.ly/2MJ4zAY).

The S-Bahn ETCS study, concluded in 2019, became the ignition point for Stuttgart Digital Node (*Digitaler Knoten Stuttgart*, DKS)

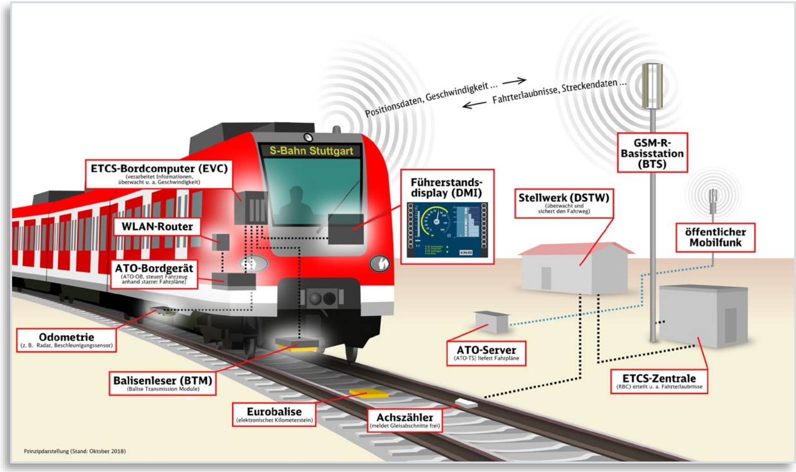

Untersuchung zur Einführung von ETCS im Kernnetz der S-Bahn Stuttgart
Abschlussbericht

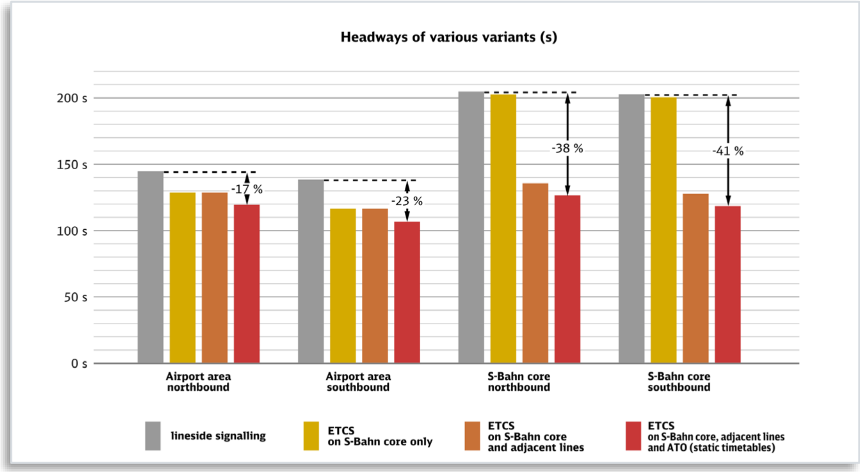
Version 2.0 vom 31.01.2019

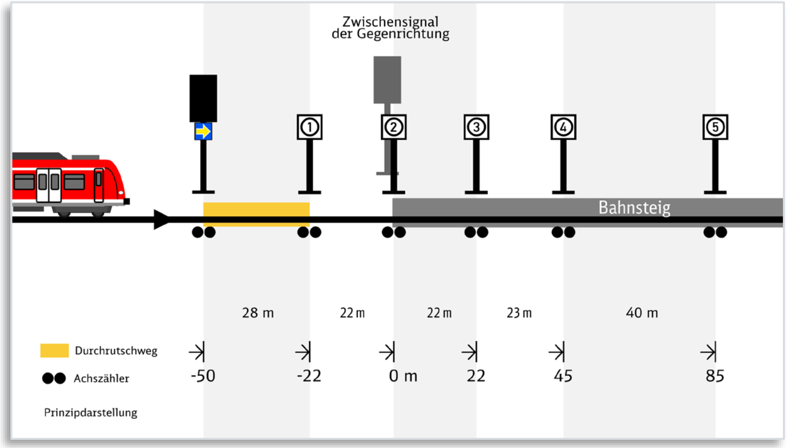
Vorgangs-Nr.: 17FEI27440

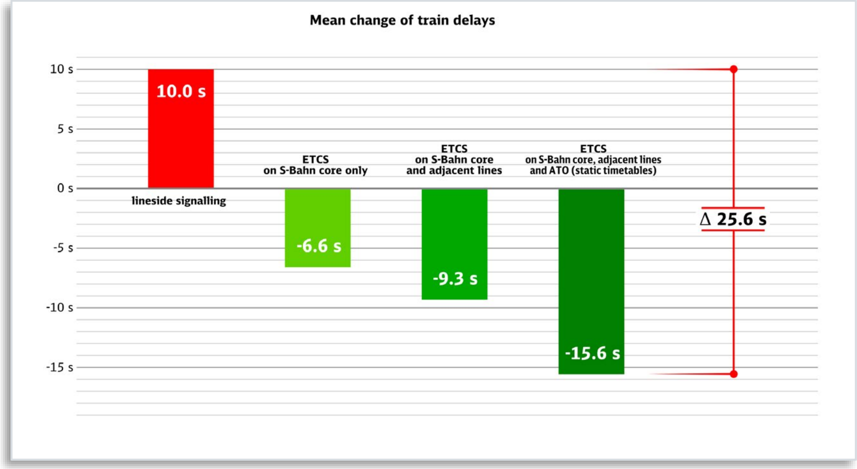
Ingenieurgemeinschaft:

- WSP Infrastructure Engineering GmbH
- NEXTRAIL GmbH
- quattron management consulting GmbH
- VIA Consulting & Development GmbH
- Railistics GmbH



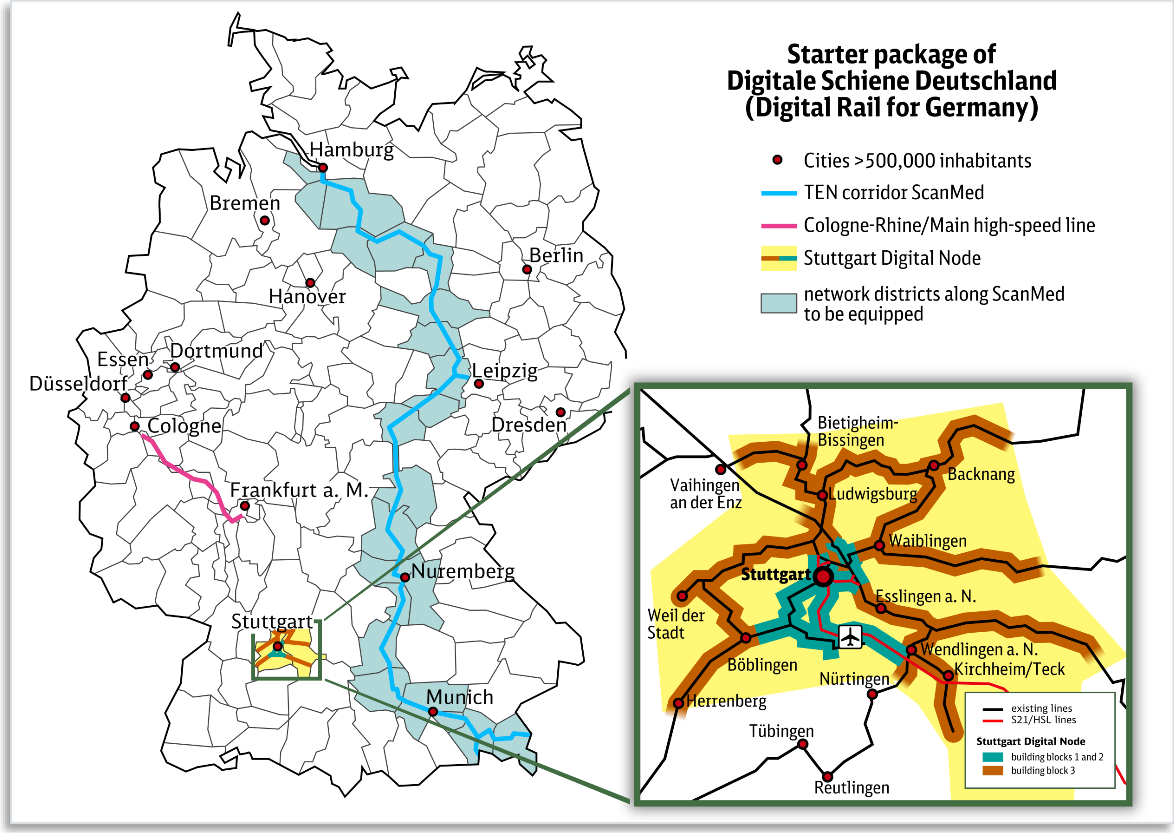


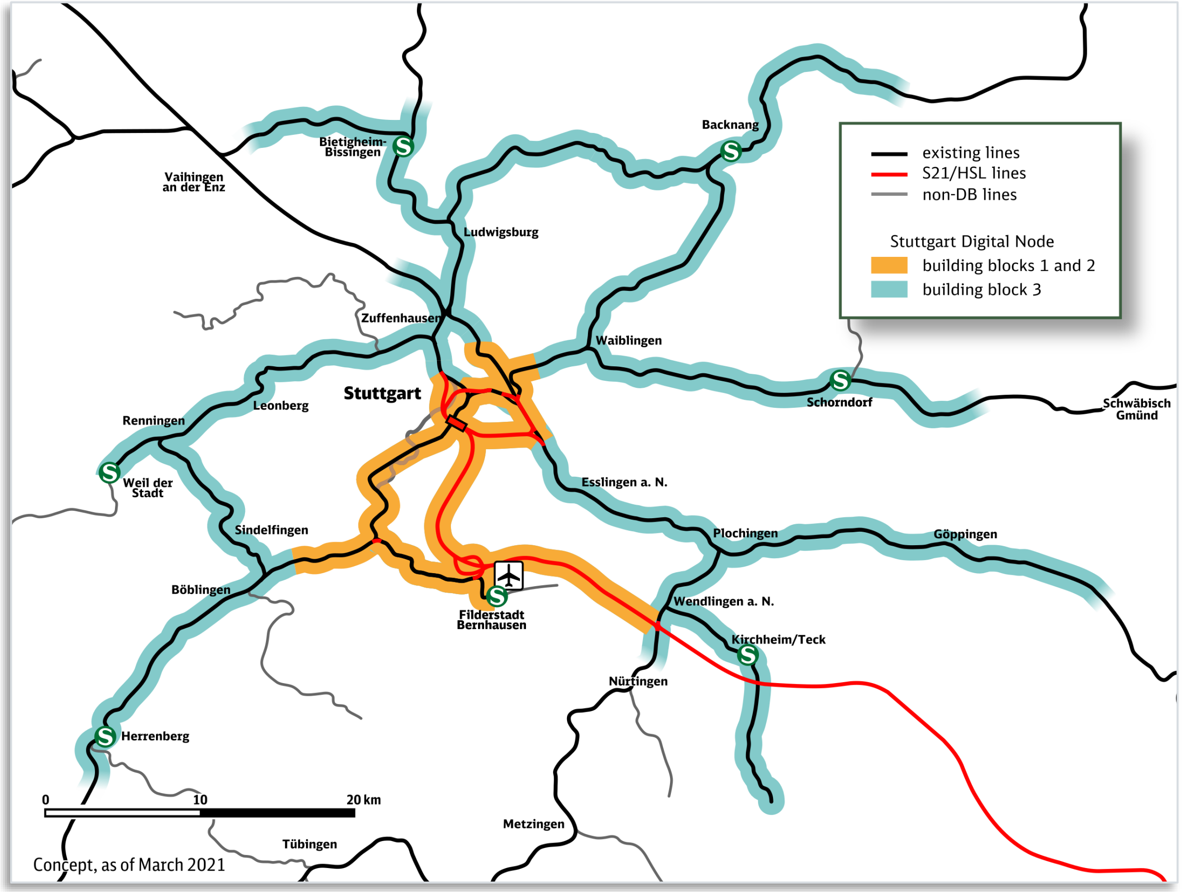




Left figure: Cover of the final S-Bahn ETCS study report (in German), dated Januar 31st 2019 (https://bit.ly/2Yyaw6h).
Further reading: *ETCS as a carrier system for improved performance at S-Bahn Stuttgart*. Signal+Draht 6/2019 (https://bit.ly/2MJ4zAY).

DKS is a pilot scheme in the starter package of Digitale Schiene Deutschland (DSD), covering some 500 km of the DB network, ranging from European corridors to single-track rural lines.

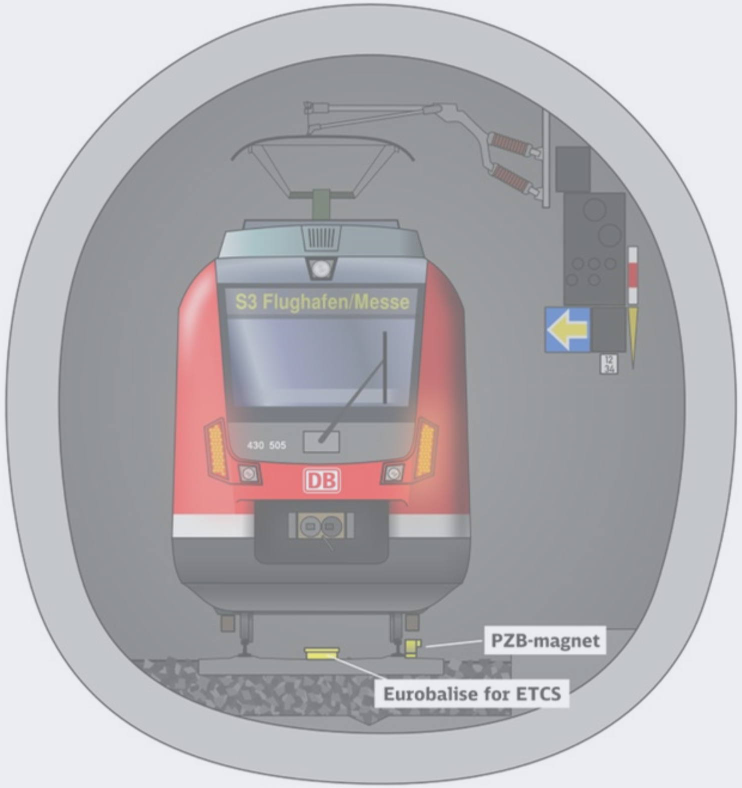




Further reading: *Stuttgart leads the way in German ETCS rollout*. International Railway Journal 4/2023.

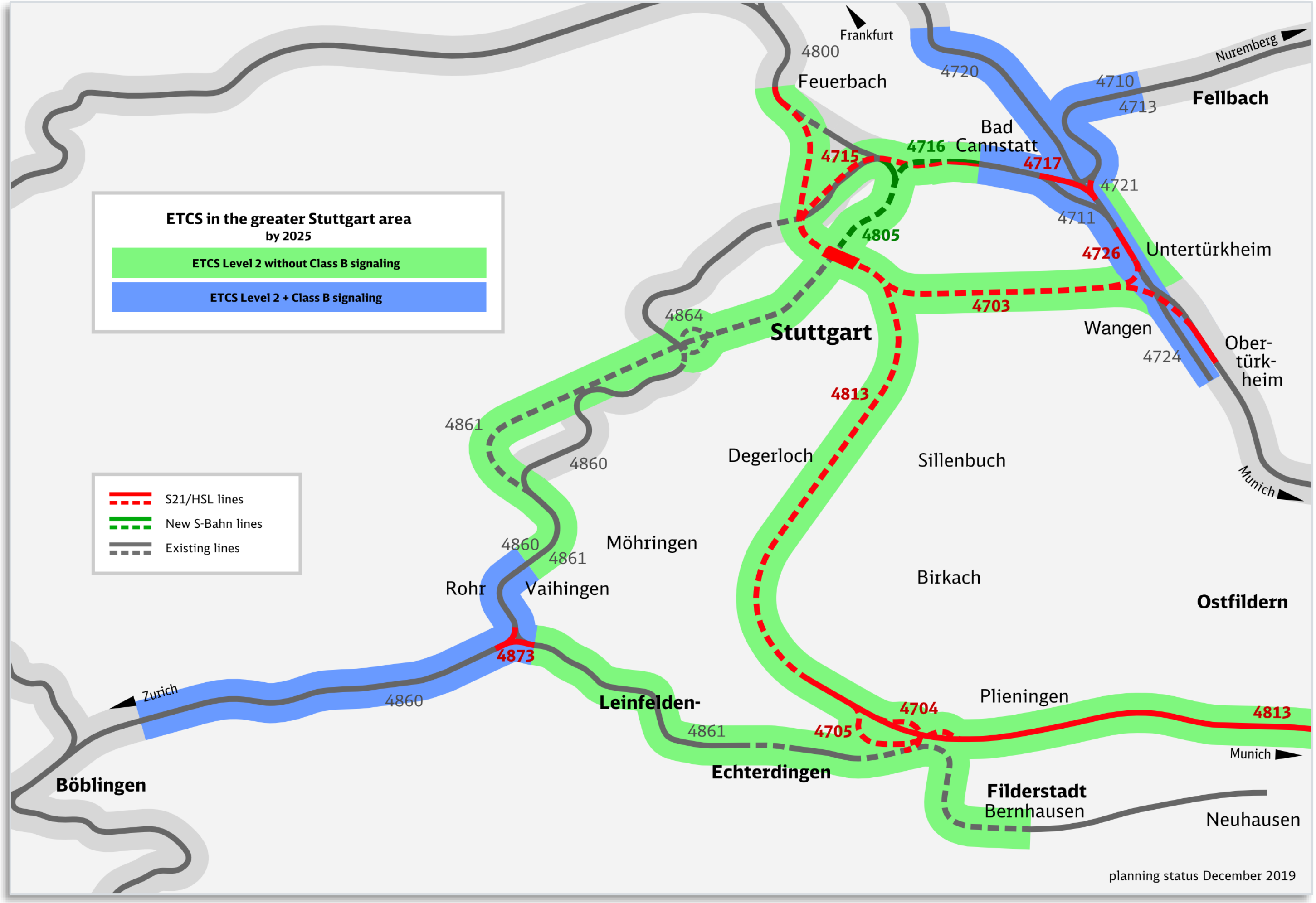
Early on, we decided to go for ETCS L2 without Class B signalling (wherever possible) – fully aware of the many issues attached to it.

S-Bahn tunnel
ETCS signalling



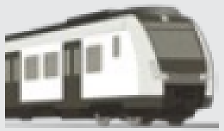
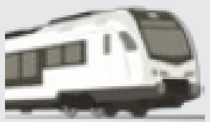
S-Bahn tunnel
both lineside and ETCS signalling

In 2025, the centre of DKS will be gradually put into service. We expect to then run some 1,700 passenger trains per day in ETCS (w/o class B).



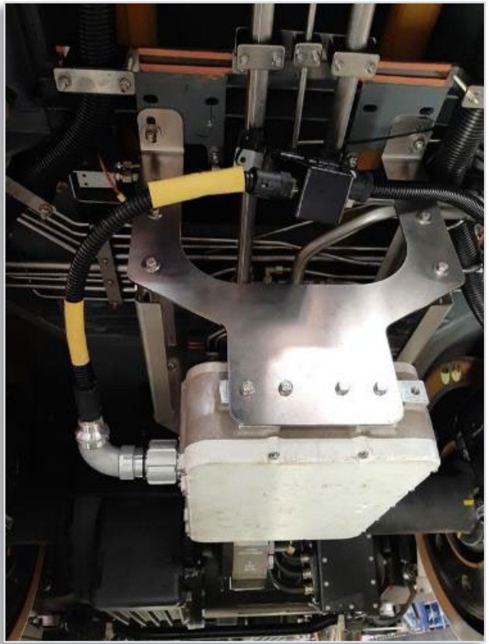
Further reading: *ETCS in large stations using the example of Stuttgart Central Station*. Signal+Draht 4/2021 (https://bit.ly/3fiozoJ).

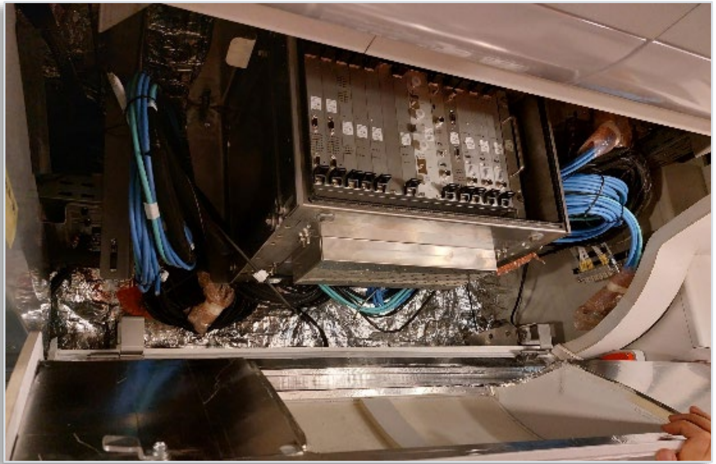
Aside of the infrastructure, vehicles are an integral part of DKS: 333 EMUs are to be retrofitted by 2025.

	Type	Number	Manufacturer	Commissioning	Configuration	Owner	Operator	Train protection
	Class 423	60	Bombardier /Alstom	1999 –2005	4-part	DB Regio	DB Regio	PZB
	Class 430	97	Bombardier	2011—2016	4-part	DB Regio	DB Regio	PZB
		58 (2nd series)	Bombardier	from 2022				
	Flirt 3	13	Stadler	since 2018	3-part	SFBW	Go-Ahead	PZB
		9		since 2018	4-part			PZB, LZB
		19		since 2018	5-part			PZB
		14		since 2018	6-part			PZB, LZB
		11		since 2019	„XL“, 3-part			PZB
	Talent 3	26	Bombardier	since 2019 (pilot since 2017)	3-part	SFBW	SWEG	PZB
		26			5-part			PZB

Further reading: *Innovative cooperation for the vehicle equipment at Stuttgart Digital Node*. Signal+Draht 9/2022 (https://bit.ly/3dxD0Z6).

The vehicle equipment for DKS includes much more than just ETCS. It is considered a blueprint for DSD.





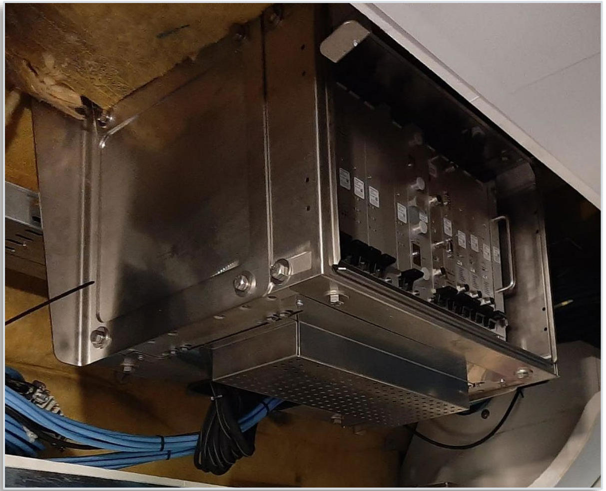
Key technical features of the DSD equipment for the core of DKS (333 retrofitted & 130 new trainsets):

- Two-staged ETCS equipment:
  - Baseline 3 R2 (SRS 3.6.0) for the start of DKS in 2025
  - TSI CCS 2023 upgrade (including Baseline 4 and FRMCS) after 2025 (already included in contracts).
- Highly automated driving (ATO GoA 2)
- FRMCS
- Train integrity monitoring (TIMS) and ETCS Level 3
- Train Capability Reports (TCR) for Capacity & Traffic Management System (CTMS)
- Standardized interfaces (OCORA, SUBSETS 119/139)
- Numerous optimizations, such as braking curves, quick Start of Mission, Cold Movement Detection...

Mere ETCS accounts for ~90 % of the cost of the series fitment, all further optimizations for only about 10%.

Some impressions of the retrofit of DB Class 423 (S-Bahn): balise antenna, EVC mounted underneath the roof, antenna for FRMCS on the roof
Further reading: *Innovative cooperation for the vehicle equipment at Stuttgart Digital Node*. Signal+Draht 9/2022 (https://bit.ly/3dxD0Z6) and *FRMCS equipment of 463 multiple units for the Stuttgart Digital Node*. Signal+Draht 5/2023 (https://bit.ly/3C5ZetG).

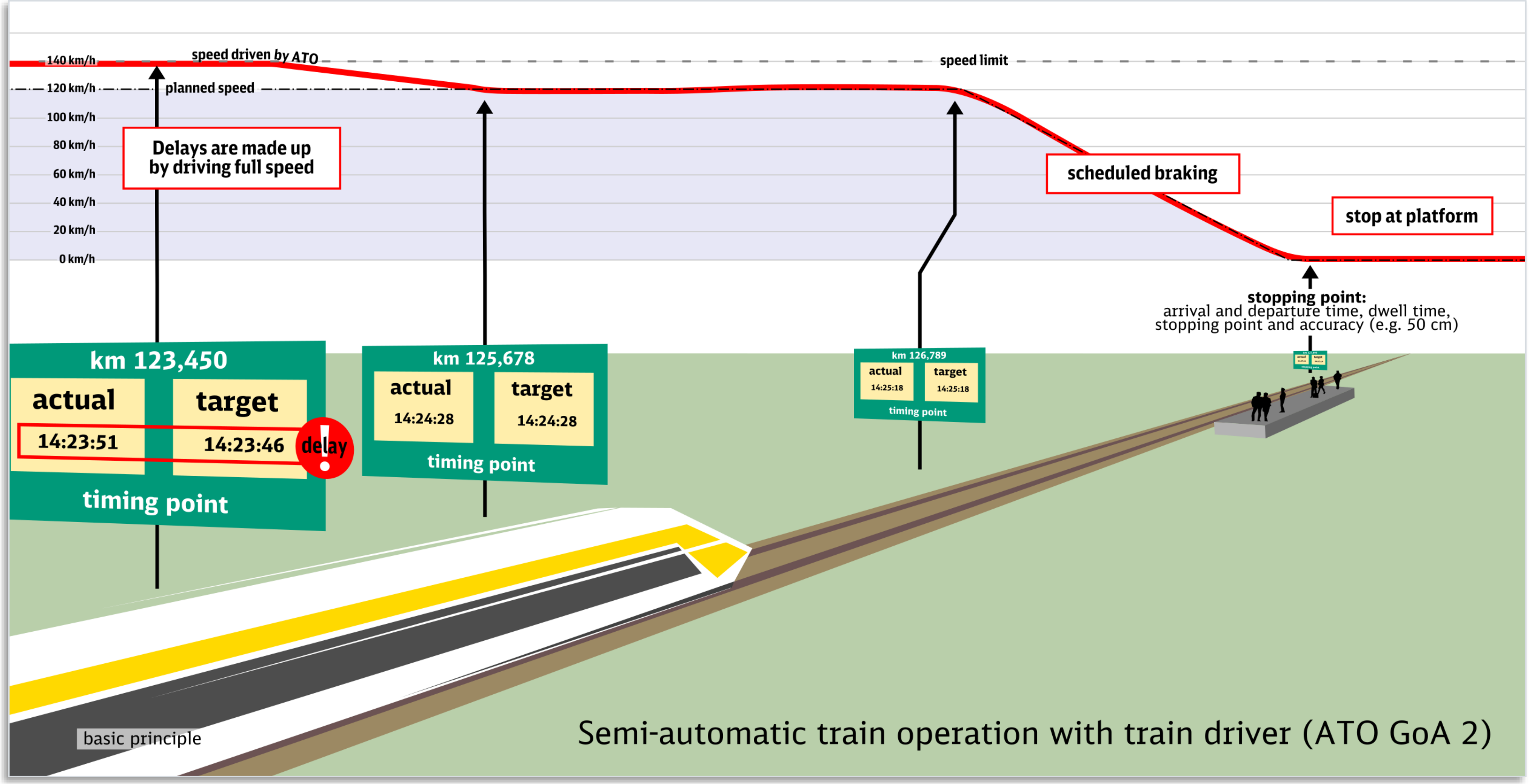
DKS is on its way and gaining further momentum.


An ETCS/ATO computer (EVC) underneath the roof.

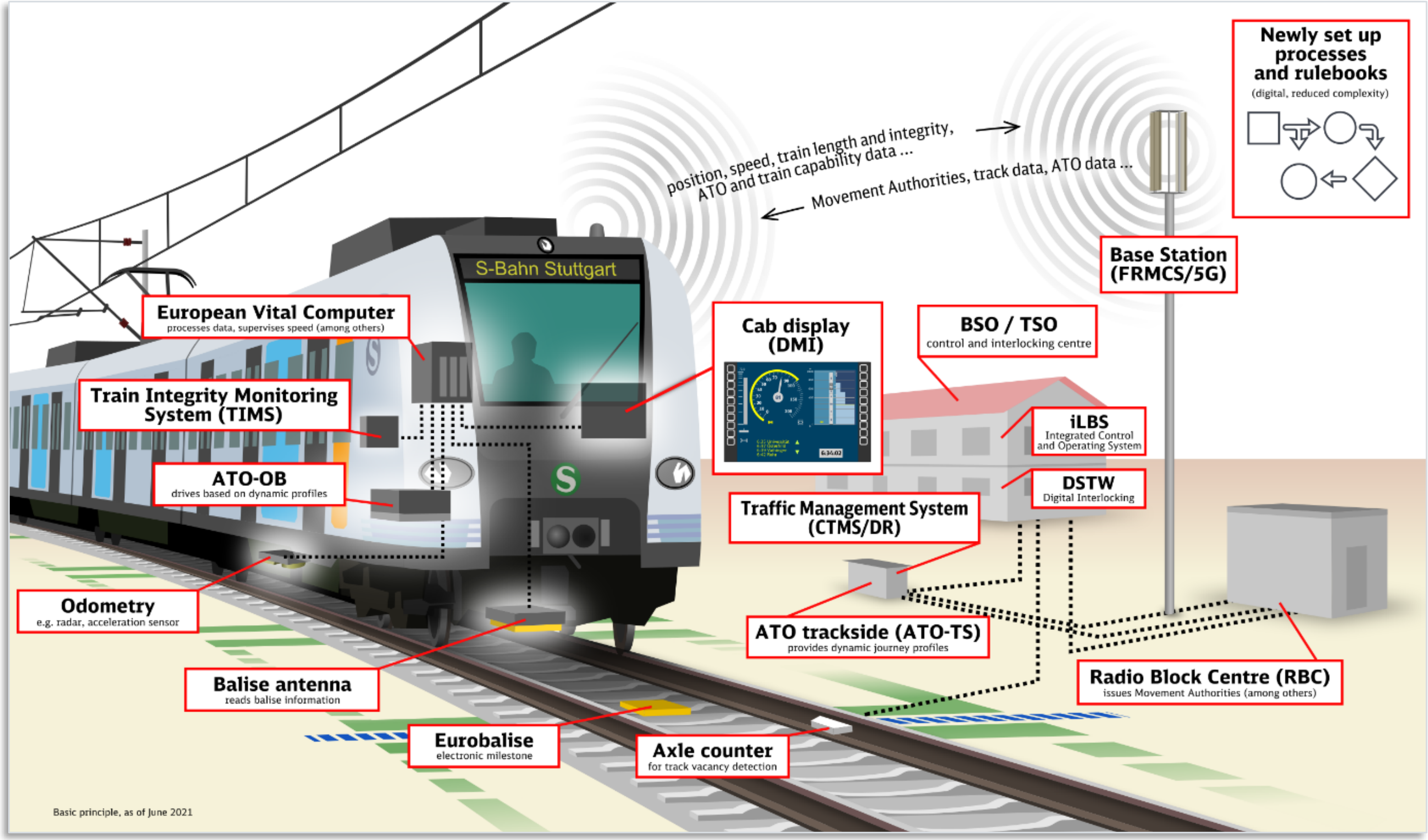

A modular building for a track-field concentrator (GFK)

- In November 2020 the centre section of the signalling infrastructure has been awarded to Thales. Field implementation has commenced.
- In mid 2021 the ETCS/DSD retrofit of 333 regional and S-Bahn trains has been awarded to Alstom. Meanwhile, 16 trainsets are being retrofitted and tested (First of Class + prototypes). In addition, 130 new double-deck regional trains awarded to Alstom will be fully fitted from the start.
- Interlockings, ETCS and further technologies are gradually put into operation, from early 2024 to 2030.
- In “innovative cooperations” some topics have jointly been developed to application maturity, such as new route types, FRMCS vehicle equipment and performance improvements.
- Funding for the infrastructure and a first batch of vehicles (for 2025) is mainly provided by the Federal Republic of Germany, supported by the EU, the state of Baden-Württemberg, the Stuttgart region and Deutsche Bahn. Funding for further vehicle equipment (beyond 2025) and some key technologies for the entire DB network (such as a full-scale Traffic Management System) is yet to be solved.

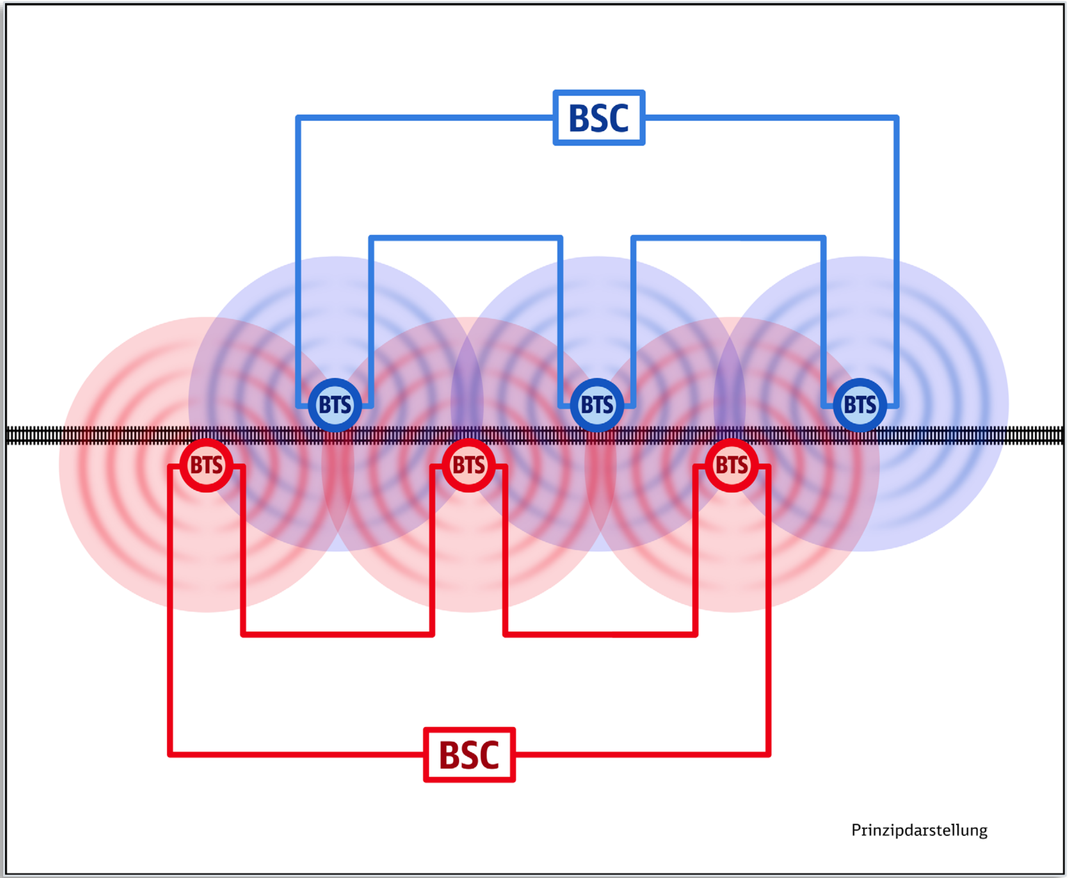
In DKS new interlockings and ETCS serve as a basis for further technologies and optimizations: such as ATO GoA 2.

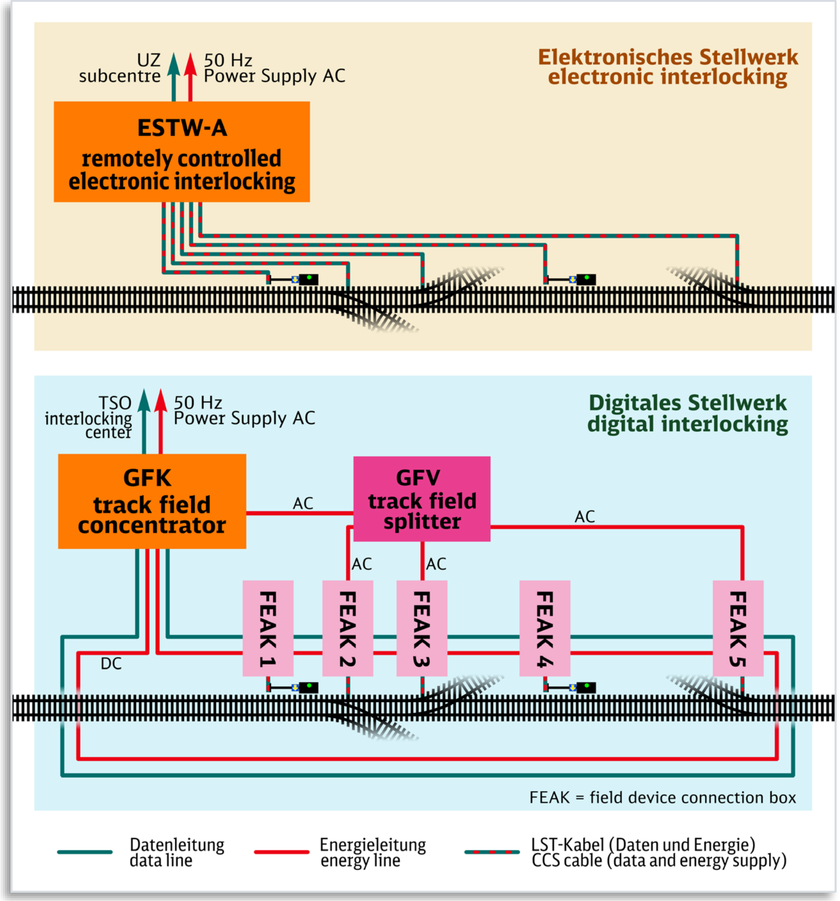


The overall system (simplified, 2030 horizon) rests on three pillars: vehicles, infrastructure and new operational rules



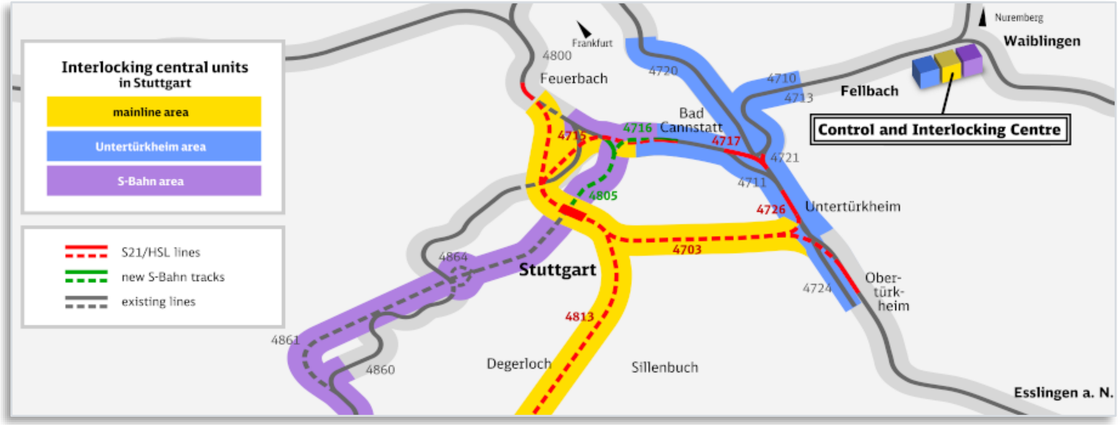
Two out of many aspects of a resilient “digital” railway: fully redundant GSM-R, field elements connected in rings

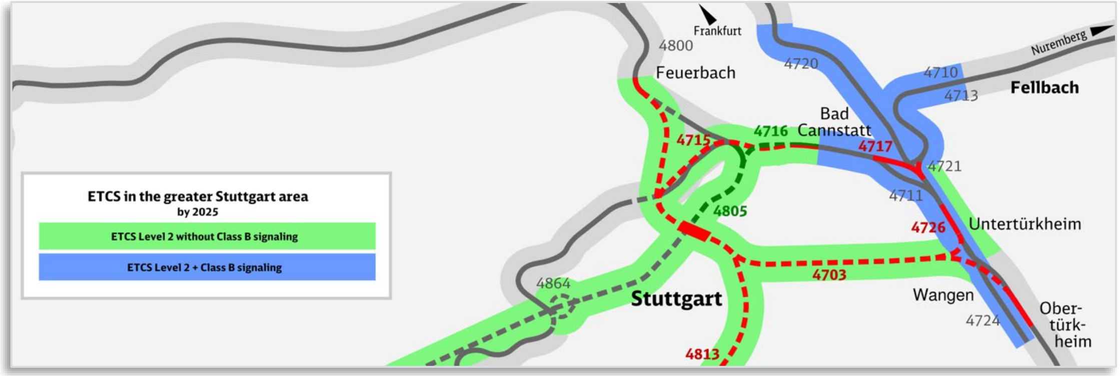




Further reading: *Experience gained from track field networking at the Stuttgart Digital Node (part 1)*. Signal+Draht 4/2023 (https://bit.ly/41Mlkgb).

The new (EULYNX-based) interlocking is particularly robust, but leads to an enormous amount of cabling in some cases.

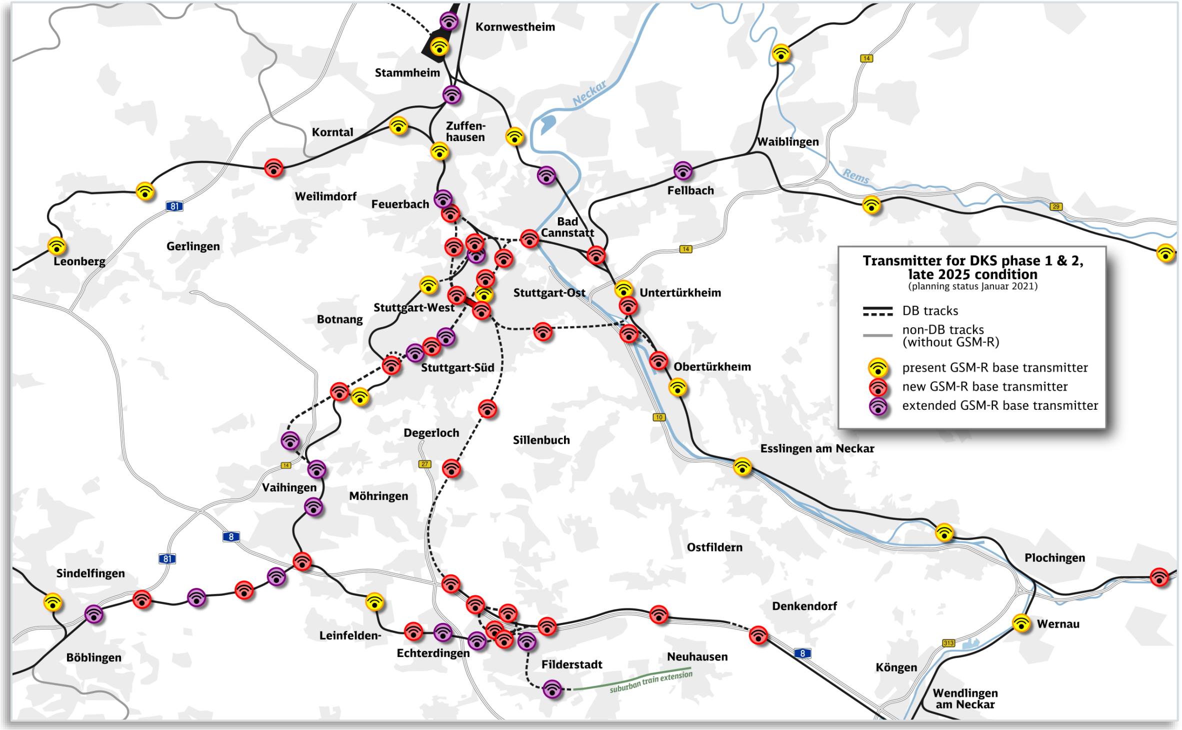




- The Untertürkheim control area (blue in top figure), which is characterized by larger stations, will temporarily be signaled both with ETCS L2 and class B/lineside signals (blue in lower figure).
- It is scheduled to be put into service in early 2024. The temporary class B equipment leads to approximately a tripling of the cabling effort compared to an ETCS-only system.
- All the optimizations taken in the meantime were ultimately not sufficient to meet the commissioning date of early 2024.
- Therefore large-scale closures, between the end of April and the end of July, were announced in mid March.
- In addition to further optimizations, the experiences underline the urgent recommendation to skip lineside signalling/class B in the infrastructure wherever possible.

Further reading: *Experience gained from track field networking at the Stuttgart Digital Node (part 1)*. Signal+Draht 4/2023 (https://bit.ly/41Mlkgb).

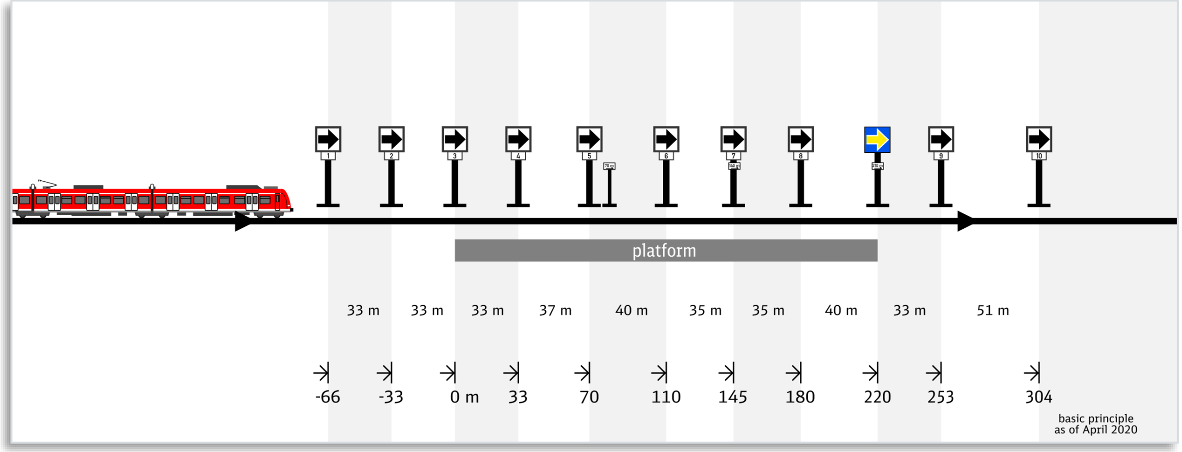
No big deal: making GSM-R work for full-scale ETCS L2 operation in the core of the Stuttgart Digital Node

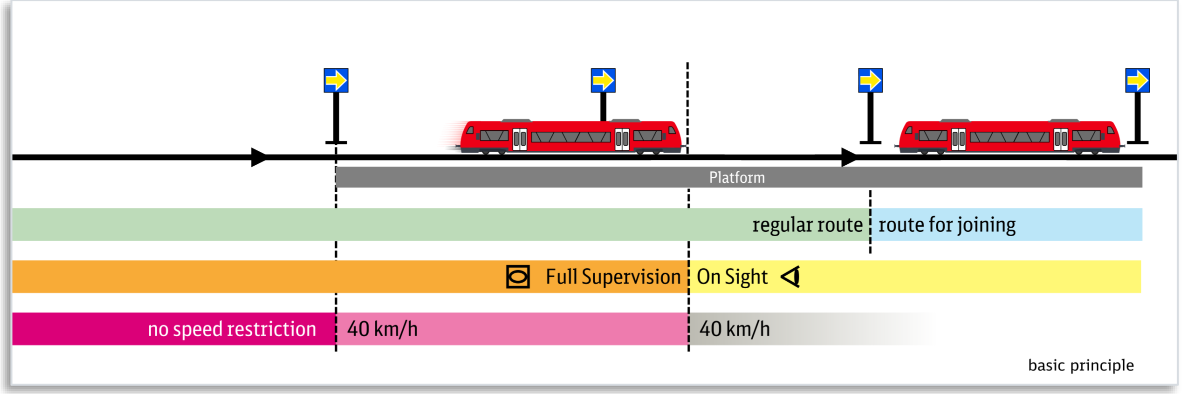


- For DKS, the railway radio network in Stuttgart is extensively redesigned (see image).
- DKS makes use of the extended GSM-R band which is available in Germany.
- Therefore, 19+15=34 carriers (“frequencies“) are available, each supporting some 6 trains in ETCS simultaneously.
- No GPRS is needed, providing slightly shorter system delays and more predictable handovers.
- FRMCS planning has recently commenced for parts of the DKS. However, several key design issues are yet to be clarified.

Further reading: *ETCS in large stations using the example of Stuttgart Central Station*. Signal+Draht 4/2021 (https://bit.ly/3fiozoJ).

Three out of many performance optimizations: short blocks, new route type for joining, improved braking curves





ALSTOM
· mobility by nature ·

CT4045 SBS-ETCS Onboard

2.3 Dreifachtraktion

Zuglänge	205 m
Bremshundertstel	150
Brake Position (Passenger train in P, freight train in P oder freight train in G)	Passenger train in P
Nominale Schnellbremsverzögerung A_brake_emergency(V)	see table below
Sicherheitsfaktor auf trockener Schiene Kdry_rst(V,EBCL)	see table below

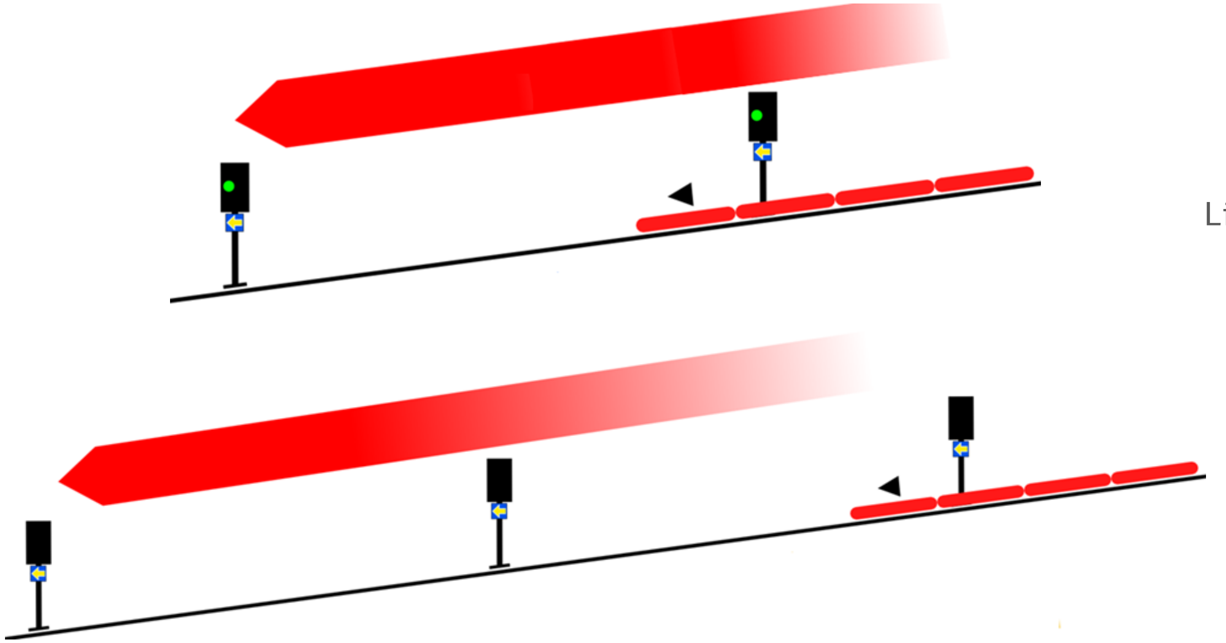
Geschwindigkeit [km/h]	140-120	120-100	100-80	80-50	50-30	30-15	15-0
A_brake_emergency [m/s²]	1,01	0,95	0,93	0,95	1,00	1,06	0,95

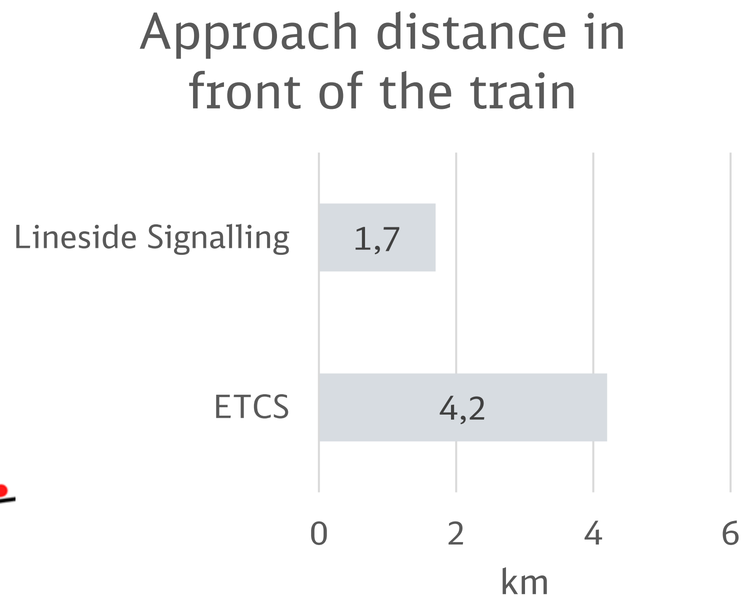
	Geschwindigkeit [km/h]	140-120	120-100	100-80	80-50	50-30	30-15	15-0
Kdry_rst(V,EBCL)	EBCL = 0	1	1	1	1	1	1	1
	EBCL = 1	0,97	0,97	0,97	0,97	0,97	0,97	0,97
	EBCL = 2	0,94	0,94	0,94	0,94	0,94	0,94	0,94
	EBCL = 3	0,92	0,92	0,92	0,92	0,92	0,92	0,92
	EBCL = 4	0,90	0,90	0,90	0,90	0,90	0,90	0,90
	EBCL = 5	0,88	0,88	0,88	0,88	0,88	0,88	0,88
	EBCL = 6	0,85	0,85	0,85	0,85	0,85	0,85	0,85
	EBCL = 7	0,81	0,81	0,81	0,81	0,81	0,81	0,81
	EBCL = 8	0,80	0,80	0,80	0,80	0,80	0,80	0,80
	EBCL = 9	0,78	0,78	0,78	0,78	0,78	0,78	0,78

Top left: Short blocks at S-Bahn platform tracks – see: *Optimising block division with ETCS Level 2 in the Stuttgart Digital Node*. Signal+Draht 7+8/2021 (https://bit.ly/3Ai0gQR).
Bottom left: New route type for joining (ETCS without class B) – see: *Innovative cooperation for the CCS infrastructure at the Stuttgart Digital Node*. Signal+Draht 7+8/2022 (https://bit.ly/3PR8NRF).
Right: Some impressions from a Gamma braking model for a S-Bahn train – publicly available at https://digitale-schiene-deutschland.de/Digitaler-Knoten-Stuttgart

A mere ETCS on-board equipment can lead to capacity losses, e.g. due to flat braking curves.

An (extreme) example of a real train expected in the heart of DKS,
on the approach the new main station in 25 permille gradient at 160 km/h:

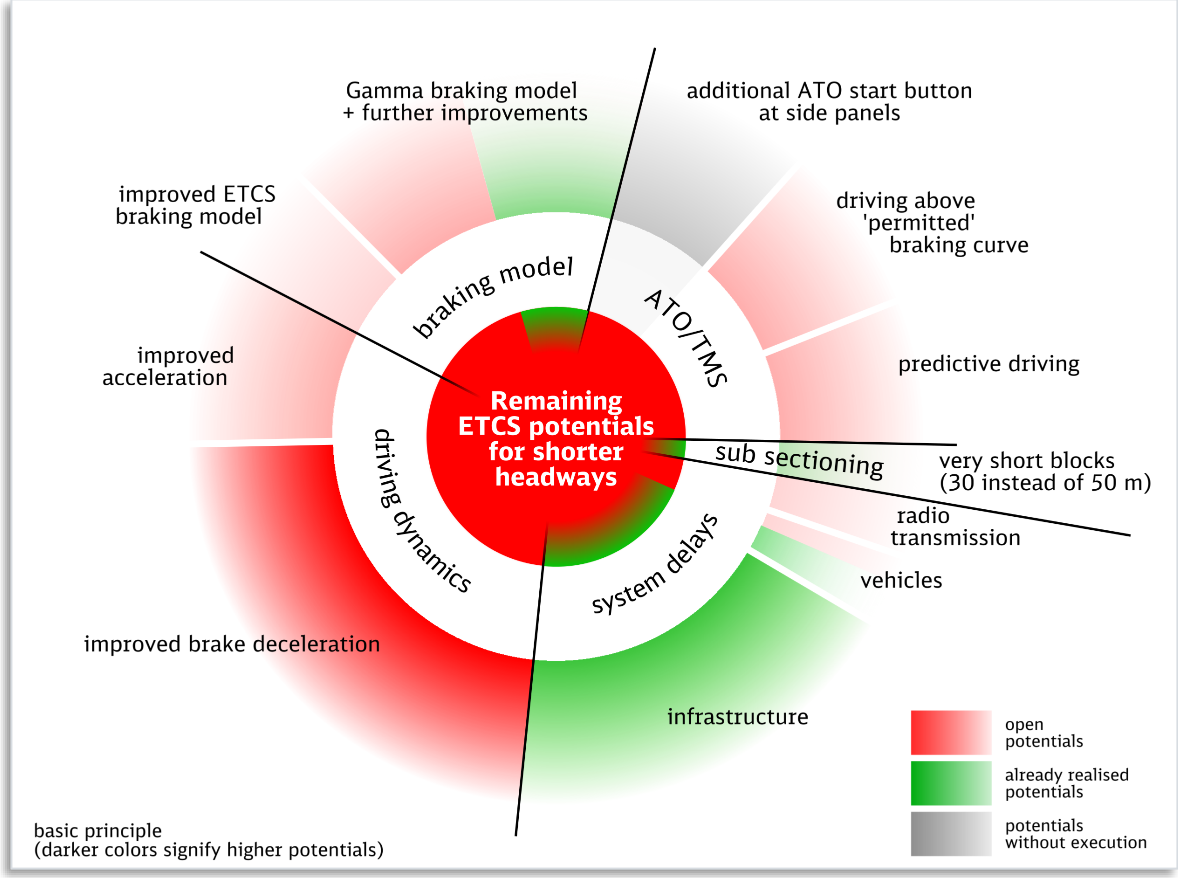




With ETCS, the train consumes significantly more capacity in the approach to Stuttgart central station than with lineside signaling.

Necessary braking distance in front of the train for unimpeded travel (pre-signalling) as assumed in the timetable design.
Lineside signaling: 1.2 km typical advance signal distance (former planning in the Filder Tunnel) plus 12 s visibility time at 160 km/h.
ETCS: Indication braking curve from 160 km/h, derived from guidance curve of 0.5 m/s² in 25 per mille gradient => braking deceleration of around 0.25 m/s².

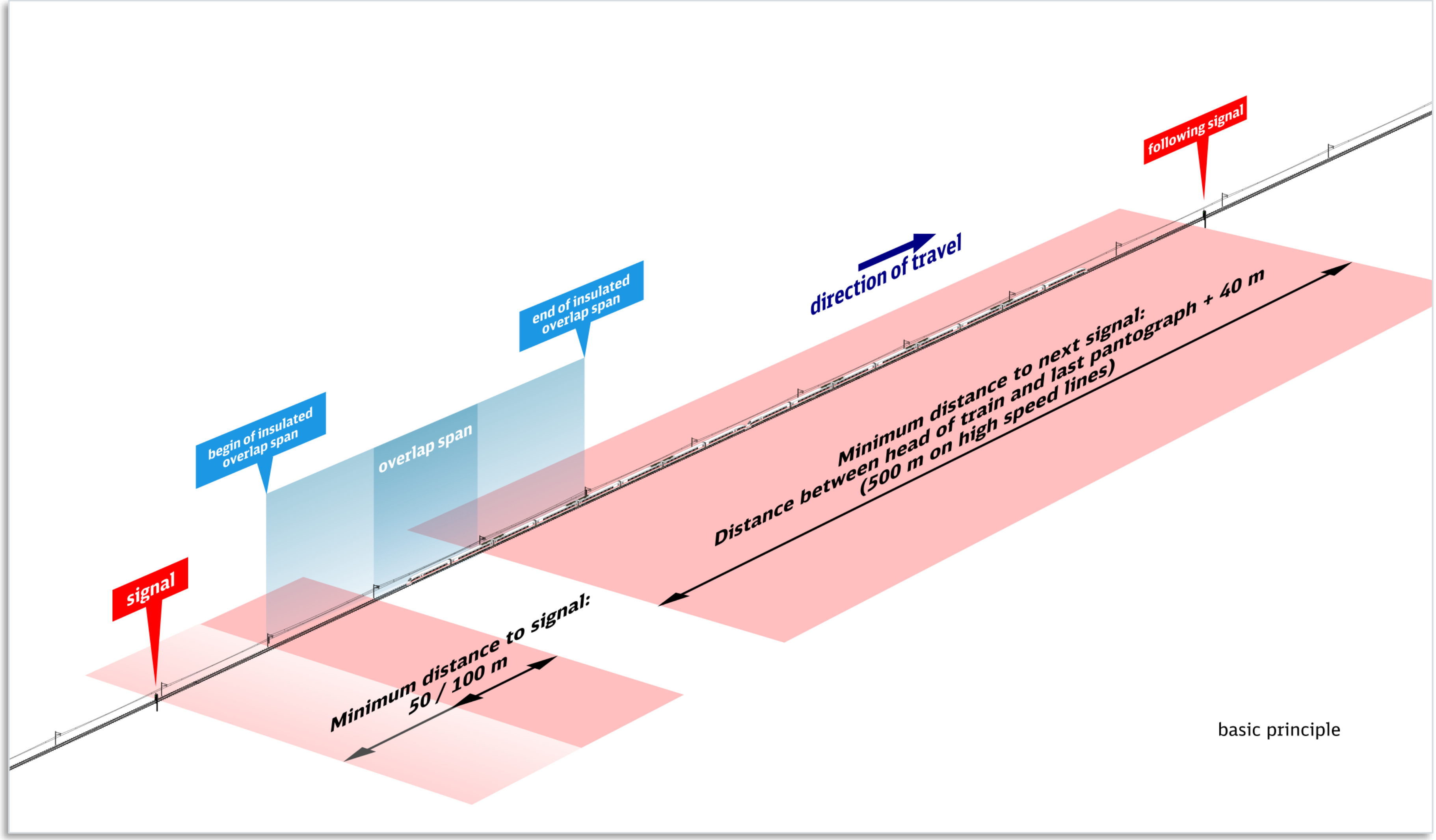
Significant capacity gains have been achieved: such as some 35 % more capacity for the Core of the S-Bahn system



Not all potentials are shown, such as better localisation than originally assumed (about 5 instead of 55 m of modeled odometry inaccuary) and mere potentials for quality (such as greater speeds for rains running late).

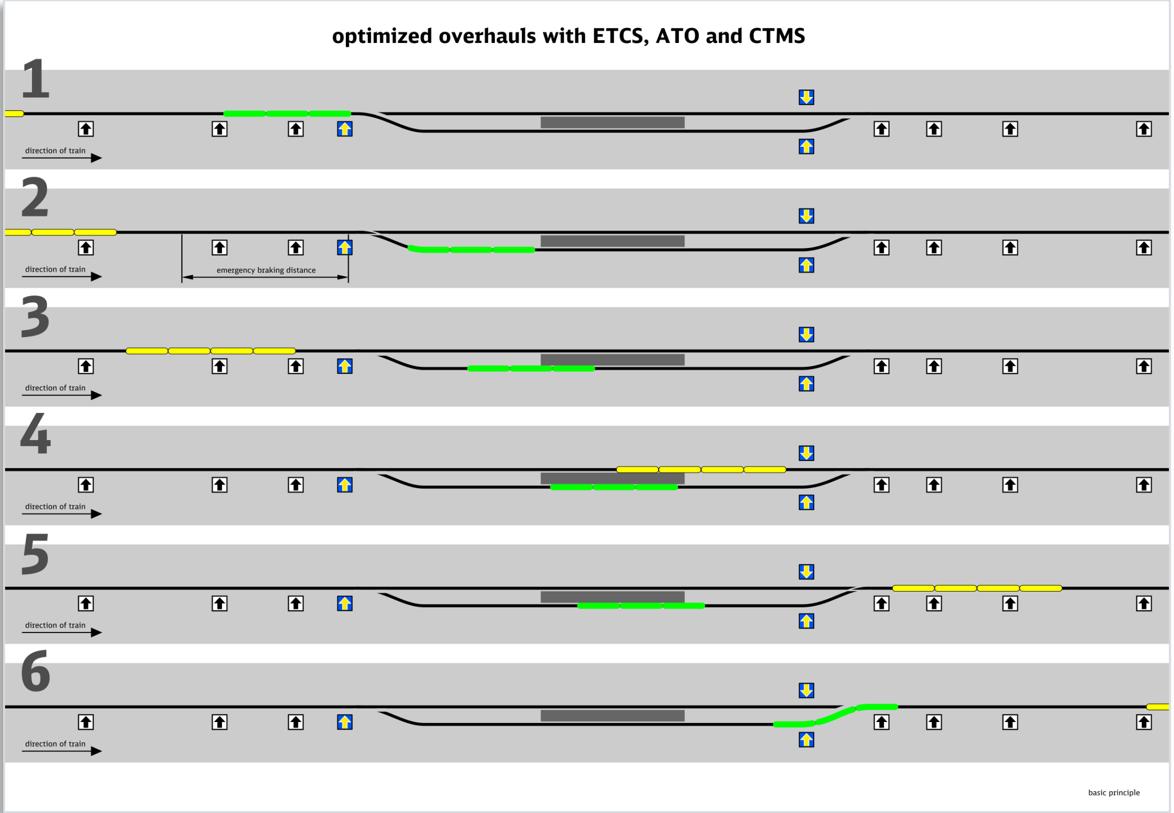
- In 2018, the S-Bahn ETCS feasibility study concluded at some 20 percent capacity gain through ETCS Level 2 and ATO GoA 2 (compared to lineside signalling).
- Since then, further potentials have been raised, such as improved system delays, block division and braking curves (green in figure). With these potentials, a ~35 percent reduction in headways can be achieved.
- Further potentials are still being examined (red in figure).
- Almost all of the improvements require rely on a the vehicle equipment (to at least some degree).
- The questions is no longer *if* we will achieve 50 percent more (peak hour) capacity through full-scale CCS optimization, but only *how*. – Even no further “digital” potentials will be raised, much improved driving dynamics of future vehicles would be sufficient to do the job.

The devil is in countless details: such as block division at section brakes in the overhead lines



Further reading: *Section breaks and level crossings limit capacity increases under ETCS Level 2*. Signal+Draht 1+2/2023 (https://bit.ly/40AY6br) and *Optimising block division with ETCS Level 2 in the Stuttgart Digital Node*. Signal+Draht 7+8/2021 (https://bit.ly/3Ai0gQR).

A whole-system approach optimisation based on ETCS, ATO and (C)TMS might lead to capacity leaps for crowded mixed-traffic lines.



- Proof has been made in a model that a suburban train (green in figure) can be overtaken by a 130 km/h regional train (yellow) during its 30-second stop.
- “Digital” optimisations include
  - ETCS (for short blocks and position reports)
  - ATO GoA 2 (driving close to the EBI where necessary)
  - Traffic Management (for real-time optimisation)
  - optimized system delays and braking curves
- “Non-digital” optimisations include 700 m tracks, points for 100 km/h and improved driving dynamics.
- To compensate for delays (and to give TMS some legroom), small optimisations in the alignment are applied to enable late trains to go faster than today, while keeping scheduled travel times unchanged.
- These methods are about to be applied to some areas of DKS.
- If it works out, even doubling the number of trains on mixed-traffic currently considered “fully occupied” might be possible.

Further reading (in German): *Maximierung der Fahrwegkapazität mit Digitaler Leit- und Sicherungstechnik*. Eisenbahntechnische Rundschau 7+8/2021 (https://bit.ly/2SIQvjY), *Optimierung von Überholvorgängen mit digitaler Leit- und Sicherungstechnik.* Bachelorarbeit Mai 2022 (https://bit.ly/3BbuPJR).

Key learning from the DKS project (so far)

Visual of the new Stuttgart central station (above) and the new Mittnachtstraße S-Bahn station. Source: plan b, Stuttgart

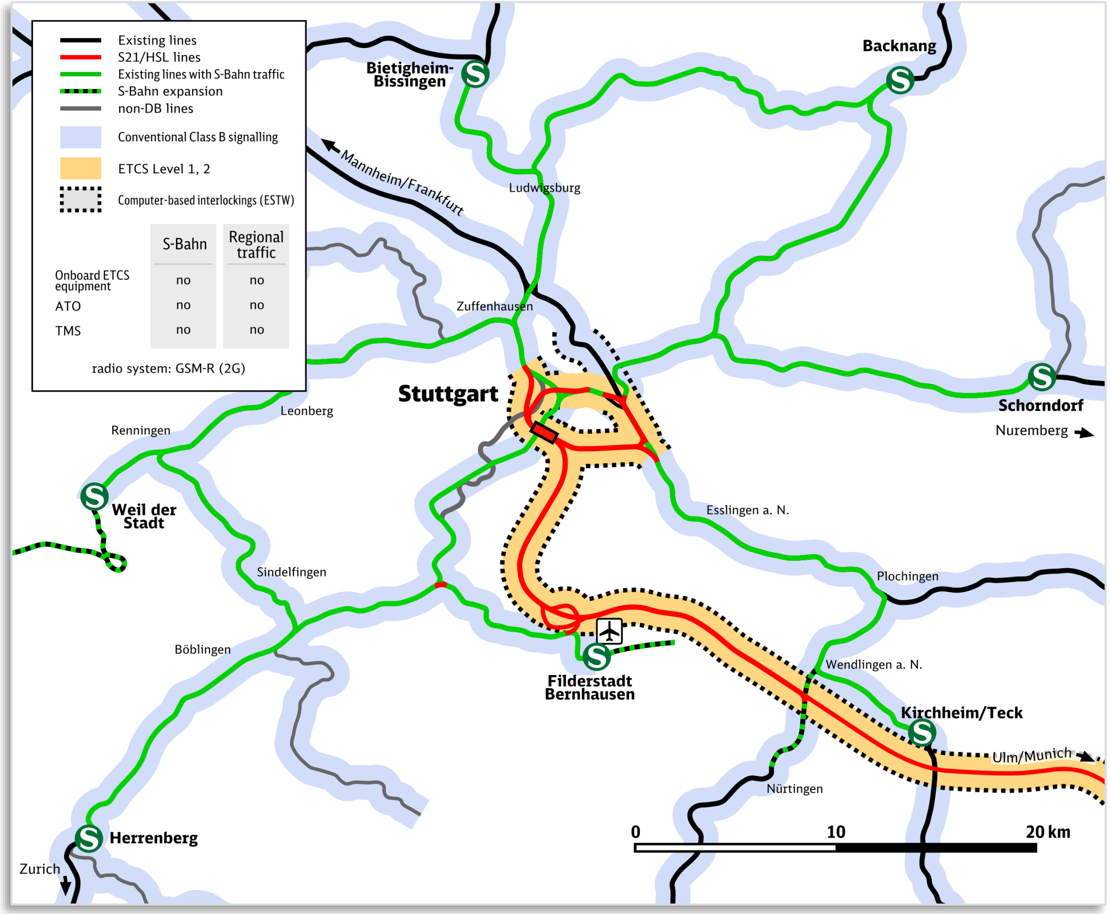
- ERTMS is suited for an urban node.
- However, “digital” not per se better. In many cases, new interlockings, ERTMS and new procedures do not lead to more, but *less* capacity.
- Major capacity gains can be achieved. However, it is not enough to somehow put ETCS on infrastructure and vehicles.
- To achieve that, we need to think the railway system as a whole: CCS infrastructure *and* vehicle equipment, ETCS *and* further technologies, CCS *and* further trades.
- About 90 percent of the cost at the heart of DKS (infrastructure + vehicles) is spent for a basic solution (interlocking + ETCS). The full set of performance and availability improvements account only for additional ~10 percent.
- If we see and optimize the railway system as a whole, we can achieve a railway that is not only easier to be planned and built, but also provides more capacity and more safety at the same time!

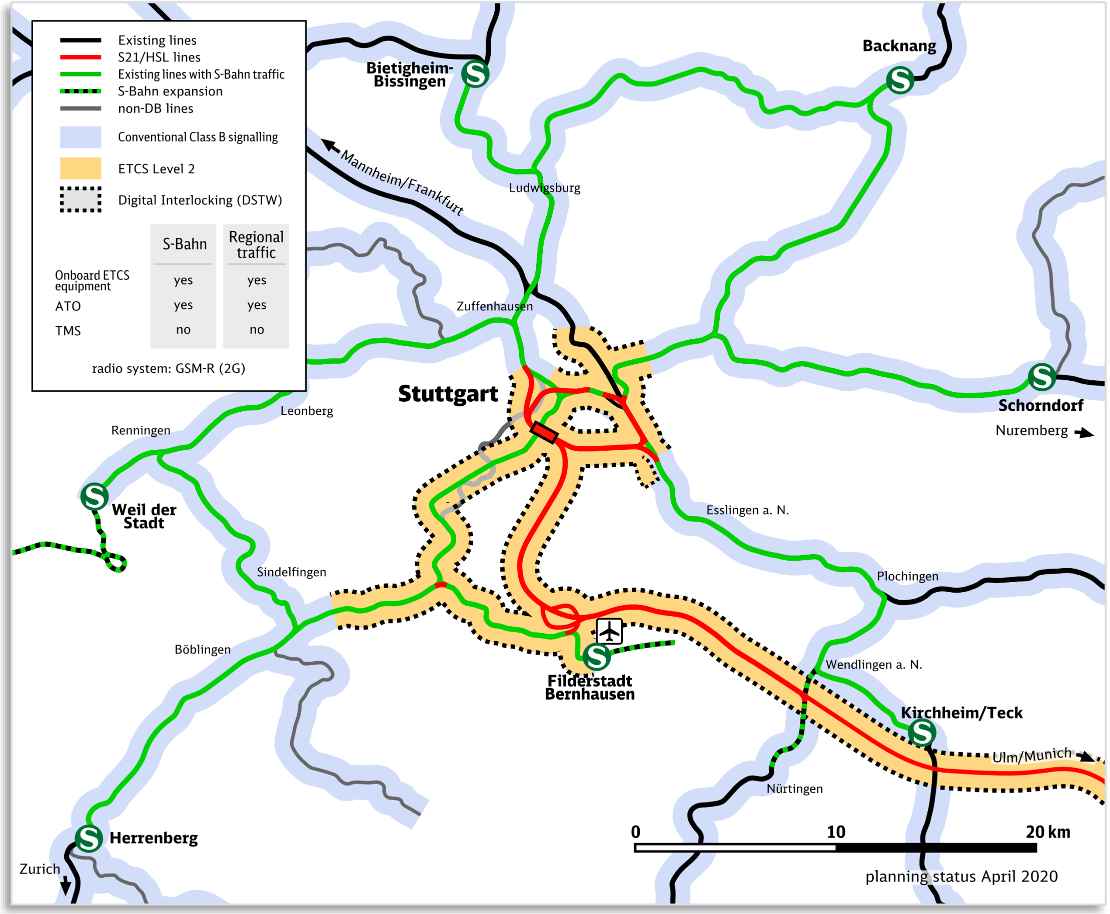
Questions?

More information:
https://digitale-schiene-deutschland.de/en/Digital-Node-Stuttgart

Picture: New Merklingen station at the Wendlingen–Ulm high-speed line (author: Arnim Kilgus)

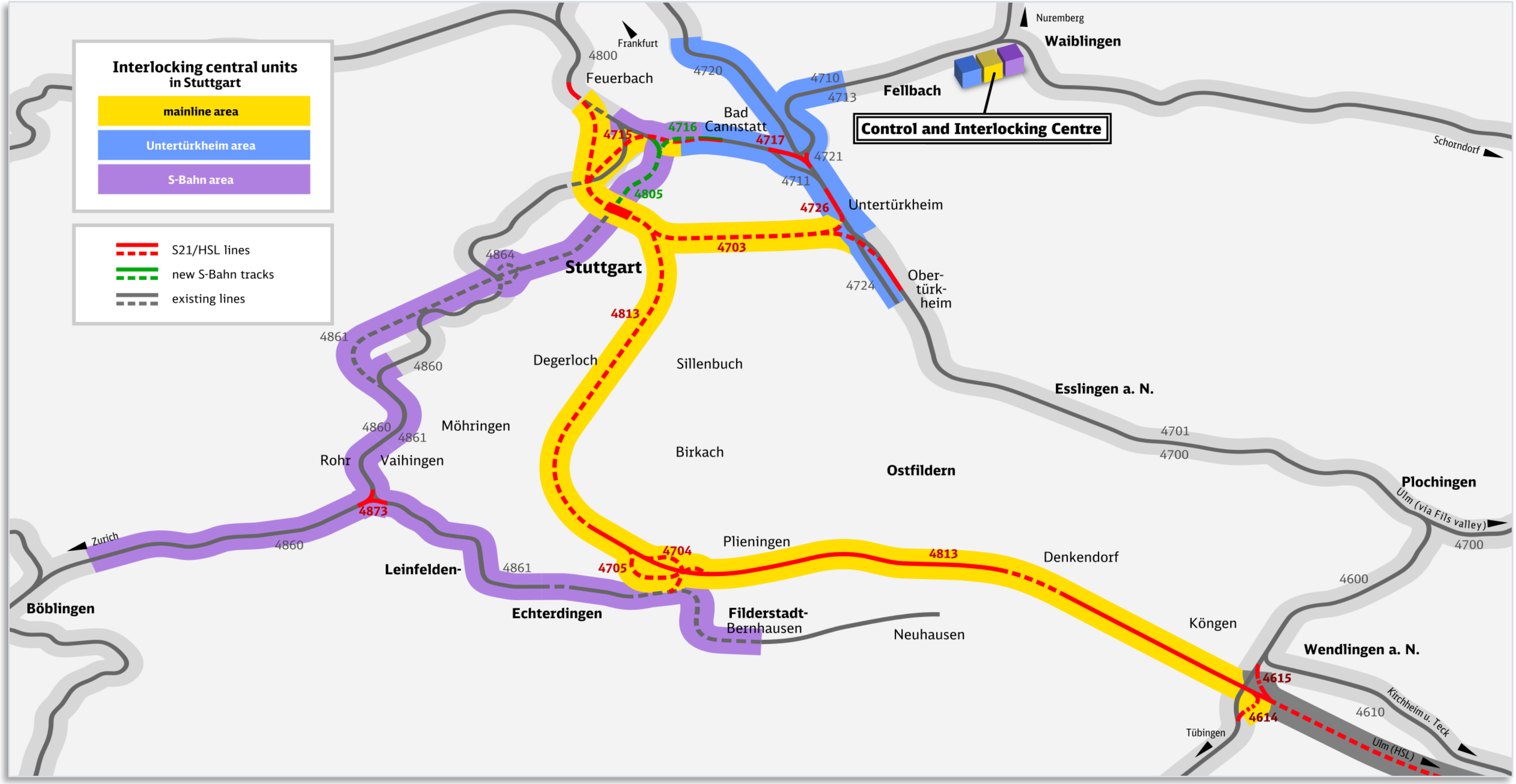
Compared to the original Stuttgart 21 concept, the DKS parts to be put into operation by 2025 reach much further.





Further reading: *Stuttgart leads the way in German ETCS rollout*. International Railway Journal 4/2023.

Three interlocking central units are to be gradually put into operation between early 2024 and late 2025.



Further reading: ETCS in large stations using the example of Stuttgart Central Station. Signal+Draht, 4/2021 (https://bit.ly/3fiozoJ)

To meet DKS' capacity goals, we need to make use and optimize all of signalling technology in the railway system – not just ETCS, not just infrastructure/vehicles.

S-Bahn Core:

Maximum headway of 90 s (or less)

(36 scheduled trains per hour)

Main station:

One train per platform every five minutes (under real conditions!)

New Stuttgart 21 lines:

Average train frequency: two minutes

Significant experience gained from (retro)fitting 463 multiple units for Stuttgart Digital Node.

Bundesanzeiger

Herausgegeben vom Bundesministerium der Justiz und für Verbraucherschutz

www.bundesanzeiger.de

Bekanntmachung

Veröffentlicht am Freitag, 5. Februar 2021

BAnz AT 05.02.2021 B2

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Bundesministerium für Verkehr und digitale Infrastruktur

Bekanntmachung der Richtlinie zur Förderung der Ausrüstung von Schienenfahrzeugen mit Komponenten des Europäischen Zugsicherungssystems ERTMS (European Rail Traffic Management System) und des automatisierten Bahnbetriebs (ATO) im Rahmen der infrastrukturseitigen Einführung von ERTMS im „Digitalen Knoten Stuttgart“

Vom 29. Januar 2021

Präambel

Die deutsche Schieneninfrastruktur ist teils veraltet und stark überlastet. Dies verursacht Rückstaueffekte, die sich nicht nur auf das deutsche Netz auswirken, sondern, weil Deutschland ein Transitland ist, auch auf den europäischen Schienenpersonen- und Güterverkehr.

Um Abhilfe zu schaffen, um mehr Verkehr von der Straße auf die Schiene zu verlagern und so den klimafreundlicheren Verkehrsträger Schiene zu stärken, stellt der Bund in den nächsten Jahren erhebliche Finanzmittel für ein ganzes Bündel von Maßnahmen zur Verbesserung der Schieneninfrastruktur zur Verfügung. Eine dieser Maßnahmen ist die modellhafte Förderung der Ausrüstung von Bestandsfahrzeugen mit ERTMS im Rahmen des Pilotprojekts Metropolregion Stuttgart (S-Bahn-Stammstrecke und Umland). Durch die simultane ERTMS-Ausrüstung von Fahrzeugen und Infrastruktur soll der „Digitale Knoten Stuttgart“ realisiert werden. ERTMS wird zur Umsetzung der Verordnung Nr. 1315/2013 der Europäischen Union zukünftig grundlegende Voraussetzung für die Nutzung der Infrastruktur in Deutschland sein. Der „Digitale Knoten Stuttgart“ ist Bestandteil des Starterpakets zur Digitalen Schiene Deutschland, mit der auch die EU-Anforderungen umgesetzt werden sollen.

Die Zugsteuerung über ERTMS setzt die digitale Kommunikation zwischen Infrastruktur und Schienenfahrzeug voraus, so dass beide koordiniert ausgerüstet werden müssen. Ziel des Modellvorhabens ist – mit der anteiligen Förderung einer Ausrüstung der Bestandsfahrzeuge mit ERTMS im Zusammenhang mit der korrespondierenden Fahrwegausrüstung – Problemstellungen, die bei der Ausrüstung von Schienenfahrzeugen im Zuge der weiteren Digitalisierung der Schiene entstehen können, frühzeitig zu identifizieren und lösen zu können. Der „Digitale Knoten Stuttgart“ (DKS) ist eine Erstanwendung mit zahlreichen Neuentwicklungen (z. B. ETCS mit HLB, ATO, Zugintegrität, standardisierte Schnittstellen, usw.). Dadurch soll der aufwendige Parallelbetrieb mehrerer Systeme zur Zugsteuerung fahrzeug- und streckenseitig auf ein Minimum beschränkt bzw. vermieden und damit Infrastrukturkosten gesenkt werden.

Die Effizienz der vorhandenen Infrastruktur – z. B. im Hinblick auf eine höhere Zuverlässigkeit oder eine engere Zugfolge – lässt sich mit Hilfe des automatisierten Bahnbetriebs (ATO – automatic train operation) weiter steigern. Das Fahren mit ATO gewährleistet, dass der zukünftige Anstieg der Fahrgastzahlen im klimafreundlichen Schienenpersonennahverkehr bedient werden kann. Die ATO-Schienenfahrzeugausrüstung schafft ferner die Voraussetzung für die spätere Einführung eines deutschlandweiten Traffic Management Systems (TMS). Daher soll im Rahmen des Modellvorhabens auch die ATO-Ausrüstung eines Schienenfahrzeugs gefördert werden, sofern diese zusammen mit einer im Modellvorhaben geförderten ERTMS-Ausrüstung durchgeführt und die Infrastruktur für ATO ausgerüstet wird. Dabei muss die Ausprägung „ATO over ETCS“ eingehalten und die ATO konform zu den EU-Vorgaben ausgeführt werden.

1. Zuwendungszweck, Rechtsgrundlage

(1) Mit der Förderung wird ein wesentlicher Anreiz gegeben, Schienenfahrzeuge, die im „Digitalen Knoten Stuttgart“ eingesetzt werden, mit ERTMS auszurüsten. Daneben wird eine ATO-Ausrüstung gefördert, wenn auf einer Infrastruktur betriebliche Leistungen erzielt werden sollen, die eine zusätzliche ATO-Ausrüstung notwendig machen. Der „Digitale Knoten Stuttgart“ umfasst räumlich und infrastrukturseitig das Gebiet gemäß Anhang 1.

(2) Mit dem Modellvorhaben sind die folgenden Förderziele verbunden:

– Frühzeitige Identifikation und Lösung von Problemstellungen, die bei der Ausrüstung von Schienenfahrzeugen im Zuge der weiteren Digitalisierung der Schiene entstehen können.

– Ermittlung der Potentiale und möglicher Kapazitätssteigerungen einer räumlich und zeitlich koordinierten Einführung von ERTMS parallel (fahrzeug- und infrastrukturseitig) im Hinblick auf eine Netzbezirk basierte Umsetzungsstrategie für die Digitale Schiene Deutschland.

– Entwicklung TSI-konformer deutschlandweiter ERTMS-Standards bei Fahrzeugausstattung und Schnittstellen.

Die PDF-Datei der amtlichen Veröffentlichung ist mit einer qualifizierten elektronischen Signatur versehen. Siehe dazu Hinweis auf Infoseite.

Figure: Cover sheet of the guideline for the pilot funding of DSD vehicle equipment in the DKS (https://bit.ly/3hX5CJx).

- In DKS, a whole system approach is pursued. Infrastructure and vehicle equipment are closely aligned and coordinated.
- In DKS, the German federal government is co-funding vehicle equipment with ETCS and other digital technologies for the first time as part of a model project. (The EU provides additional funding.)
- The funding is linked to 24 conditions for multiple units, e.g. ATO GoA 2, FRMCS and (optimized) gamma braking models.
- The first evaluation of the model project has been completed and the results have been published.
- About 90 percent of the costs of the series equipment are incurred for ETCS, all other optimizations account for only about 10 percent.
- The digital equipment of new vehicles is already financially less than half as expensive as retrofitting.